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Hard X-rays from galaxy clusters & SIMBOL-X

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Abstract. Non thermal emission from galaxy clusters demonstrates the existence of relativistic particles and magnetic fields in the Intra Cluster Medium (ICM). Present instruments do not allow to firmly establish the energy associated to these components. In a few years gamma ray observations will put important constraints on the energy content of non thermal hadrons in clusters, while the combination of radio and hard X-ray data will be crucial to measure the energy content in the form of relativistic electrons and magnetic field. SIMBOL-X is expected to drive an important breakthrough in the field also because it is expected to operate in combination with the forthcoming low frequency radio telescopes (LOFAR, LWA). In this contribution we report first estimates of *statistical properties* of the hard X–ray emission in the framework of the *re-acceleration model*. This model allows to reproduce present radio data for Radio Halos and to derive expectations for future low frequency radio observations, and thus our calculations provide hints for observational strategies for future radio and hard–X-ray combined observations.

Key words. acceleration of particles - radiation mechanisms: non–thermal - galaxies: clusters: general - X–rays: general

1. Introduction

Clusters of galaxies represent the largest virialized structures in the present Universe. Rich clusters have typical total masses of $10^{15} M_{\odot}$, mostly in the form of dark matter, while $\sim 5\%$ of the mass is in the form of a hot ($T \sim 10^8 K$), tenuous ($n_{gas} \sim 10^{-3} - 10^{-4} cm^{-3}$), X-ray emitting gas. In terms of energy density, the gas is typically heated to roughly the virial temperature, but there is also room to accomodate a non-negligible amount of non-thermal energy.

Clusters are ideal astrophysical environments for particle acceleration and cosmic rays (CR) accelerated within the cluster volume are expected to be confined for cosmological times (e.g., Blasi, Gabici, Brunetti 2007, BGB07, for a review). The bulk of the energy of these CRs is expected in protons since they have radiative and collisional life–times much longer than those of the electrons. While present gamma ray observations can only provide upper limits to the average energy density of CR protons in the ICM (e.g. Reimer et al. 2004), evidence of a non-thermal component is in fact obtained from radio observations of a fraction of galaxy clusters showing synchrotron emission on Mpc scales : Radio Halos, fairly symmetric sources at the cluster center, and Radio

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Relics, elongated sources at the cluster periphery (e.g., Feretti 2005).

Although the bulk of present data comes from radio observations, theoretically a substantial fraction of the non thermal radiation is expected from inverse Compton (IC) scattering of the photons of the cosmic microwave background (e.g., Sarazin 1999). Measuring IC emission from clusters in the hard X–rays is extremely important to derive the energy density of emitting electrons and the strength of the magnetic field when these measures are combined with radio data. Despite the poor sensitivity of present and past hard X–ray telescopes, several groups have claimed detection of hard X–ray emission (HXR) in a few massive clusters (e.g., Fusco-Femiano et al. 2004; Petrosian et al. 2006; Rephaeli et al. 2006; see also Rossetti & Molendi 2004 and Fusco-Femiano et al. 2007 for a discussion on the strength of the HXR detection in the Coma cluster).

Thanks to its sensitivity and capability to perform hard X–ray imaging SIMBOL–X will open a new era in the study of non thermal radiation from galaxy clusters. In this contribution we report first expectations on the Luminosity Functions (LFs) and number counts of HXR from clusters. We calculate only the contribution to the IC spectrum from electrons re-accelerated by turbulence in the ICM which are the responsible for the origin of Radio Halos in the context of the *re-acceleration scenario*.

2. HXR expectations from the re-acceleration scenario

2.1. Introduction

Mpc scale radio emission at the level of Radio Halos is found in a fraction of massive and merging galaxy clusters (e.g., Feretti 2005). The connection between Radio Halos and cluster mergers, the very large extension of Radio Halos and their complex spectral properties pose serious challenges to our understanding of these sources, at least when a quantitative comparison between models and data is performed.

A promising possibility to explain Radio Halos is given by the *re–acceleration scenario* (Brunetti et al. 2001; Petrosian 2001). In this scenario particles are supposed to be re–accelerated on large scales by MHD turbulence injected in the ICM during cluster–cluster mergers. Although the details of the physics of turbulence and of stochastic particle acceleration are still poorly understood, detailed calculations of Alfvénic and magnetosonic acceleration suggest taht efficient turbulent acceleration may take place in the ICM (Brunetti et al. 2004; Brunetti & Lazarian 2007).

2.2. A statistical approach

In Cassano & Brunetti (2005) and Cassano et al.(2006) we have modeled the statistical properties of Radio Halos as expected in the *re-acceleration scenario*. In these papers we derive the merging history of a large synthetic population of galaxy clusters, the turbulence injected during mergers and follow the process of stochastic acceleration of the relativistic electrons driven by this turbulence.

This allows us to get semi-analytic expectations for the LFs of Radio Halos assuming a Mpc^3 emitting region. These are given as :

$$\frac{dN_H(z,\nu)}{dV\, dP_\nu} = n_{PS} \times \mathcal{P}^{\Delta M}_{\Delta z}(\nu) \left(\frac{dP_\nu}{dM} \right)^{-1} \quad (1)$$

where $n_{PS} = n_{PS}(M,z)$ is the *Press & Schechter* mass function, $\mathcal{P}^{\Delta M}_{\Delta z}(\nu)$ is the probability to have Radio Halos emitting at frequency ν as measured in the population of synthetic clusters and $\frac{dP_\nu}{dM}$ can be derived from the radio power cluster – mass correlation. The statistical behaviour of $\mathcal{P}^{\Delta M}_{\Delta z}(\nu)$ depends on the magnetic field strength in the emitting region and on its scaling with cluster mass. The important point here is that it has been shown that present radio data can be reproduced provided that the magnetic field in the emitting region is within some allowed region in the B–b plane, where $B(M) \propto M^b$ and M is the virial mass of clusters (CBS06).

2.3. IC Hard X-ray emission

Starting from our previous statistical calculations for Radio Halos we can obtain simple estimates of the LFs of HXR as:

$$\frac{dN_{HXR}(z,P_{hxr})}{dV\,dP_{hxr}} = \frac{dN_{H}(z,P_{150})}{dV\,dP_{150}}\left(\frac{dP_{150}}{dP_{hxr}}\right) \qquad (2)$$

where the ratio between IC and synchrotron power depends on B:

$$\nu_{hxr}dP_{hxr} \approx \left(\frac{3.2(1+z)^2}{B_{\mu G}}\right)^2 dP_{150}\nu_{150} \qquad (3)$$

and where the HXRs are anchored to the synchrotron emission at ν =150 MHz as the electrons emitting around this frequency in μG fields are also the responsible for the IC emission in the hard X–rays.

Eqs.1–3 allow to obtain non K–corrected LFs for HXR. It should also be mentioned that these estimates provide lower limits (within a factor of $\approx$ 3) to the HXRs since a substantial fraction of these HXRs is expected to come from regions external to the central Mpc^3 (Brunetti et al. 2001,04; Colafrancesco et al. 2005).

The magnetic field is a crucial parameter in our calculations. Rotation Measures (RM) give values of the field of several μG, but these estimates are affected by uncertainties in the topology of the field and the spatial distribution of the thermal electrons, as well as by the subtraction of the intrinsic RM at the source (e.g., Govoni & Feretti 2004 for a review). Smaller fields, of the order of a few tenths of μG, are obtained by detection of HXR (e.g., Fusco-Femiano et al. 2004). This latter method relies on the assumption that the diffuse radio emission and the HXRs are cospatial and produced by the same population of relativistic electrons via synchrotron and IC respectively .

Although many theoretical attempts have shown that this discrepancy may be alleviated by considering the radial profile of the magnetic field strength in clusters, the correct shape of the spectrum of the emitting electrons, and possible anisotropic effects (e.g., Brunetti et al. 2001; Petrosian 2001), deep hard X-ray observations should be able to definitely solve this point.

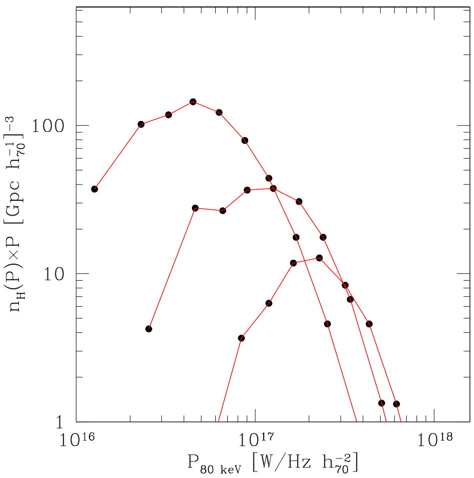

Fig. 1. LFs of HXRs in clusters. From top to bottom one has z=0.05, 0.25, 0.45 . Calculations are obtained assuming $B(M) \propto M^b$ with $B(< M >) = 0.2\mu$G, $< M >= 1.6\times10^{15}M_{\odot}$, and $b = 0.6$; this configuration is within the allowed region to match the radio–X-ray correlations of Radio Halos with the *re-acceleration model* (CBS06).

In Fig. 1 we report expected LFs of HXRs at different redshifts assuming a low value of the magnetic field in the ICM (see caption), in which case the IC luminosities are maximized. The flattening/cut–off at smaller luminosities is due to the fact that at these luminosities the LFs are contributed by clusters with masses $\leq 10^{15}M_{\odot}$ in which case the particle re-acceleration is less efficient (CBS06).

In Fig. 2 we report expected number counts by assuming two scenarios for the magnetic field in the emitting region (see caption). The important point here is that SIMBOL-X is expected to discover HXRs in $\approx 30-100$ clusters in the case of low B, while only upper limits to the presence of HXRs will be obtained for large values of B. This demonstrates the importance of future SIMBOL-X observations.

Finally, in Fig. 3 we report the redshift distribution of HXRs in the Universe for different sensitivity levels and assuming the case of low magnetic field. In this case SIMBOL-X is expected to discover HXRs in a few clusters with redshift $\approx$ 0.2, while the bulk of detectable HXRs is expected at lower redshift.

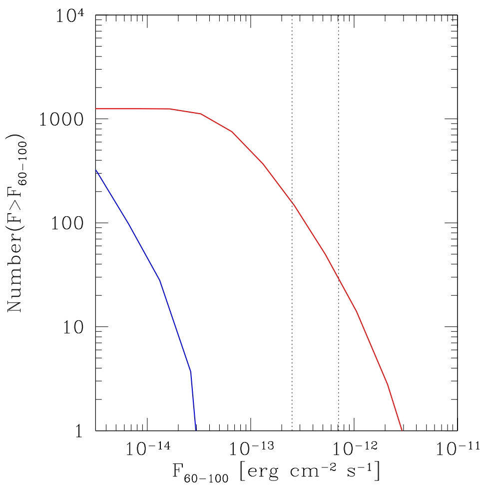

Fig. 2. Number counts of HXR. Right curve is obtained for the parameters in Fig. 1, Left curve is obtained for $b = 1.5$ and $B(< M >) = 2\mu$G. Dotted lines give a reference range for SIMBOL-X sensitivity.

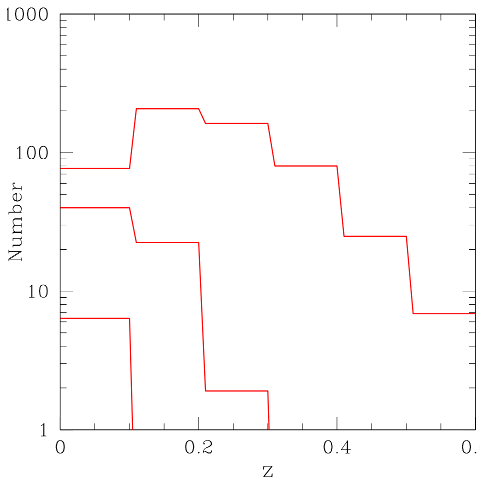

Fig. 3. Number of clusters with detectable HXR as a function of redshift. From top to bottom we assumed the following sensitivities : F_{60-100}[erg cm^{-2} s^{-1}]= 10^{-13}, 5× 10^{-13}, 10^{-12}. Calculations are obtained by assuming the parameters in Fig. 1

3. Conclusions

In this contribution we report first expectations for HXRs from galaxy clusters, a more detailed study will be reported in a forthcoming paper. Calculations are performed in the framework of the *re-acceleration model* assuming physical parameters which allow the *re-acceleration model* to reproduce present data of the statistical behaviour of giant Radio Halos.

The strength of the magnetic field in the ICM is a crucial parameter in our calculations and we have shown that SIMBOL-X will provide unique constraints. By assuming a value of the magnetic field averaged in Mpc^3 volume of $\approx 0.2\mu$G we find that SIMBOL-X will discover HXRs in ≈30–100 clusters at $z \leq 0.2$.

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